

All surfaces of the intraocular lens of the present invention are spherical. As previously discussed, the zone surface can be on the anterior or posterior face of the IOL and the non-zone surface will be on the corresponding side. The total power for distance and near vision is determined by these two surfaces of the IOL. Power, in terms of diopters, expresses the ability of the optical lens to bend light rays to a point of focus at a distance from the optic expressed as focal length. Power is inversely proportional to the effective focal length. The distance vision power for the IOL ranges from about 1 to 30 diopters. The central zone radius together with the radius of the non-zone surface determines the power of the distance vision as per the lens maker formula for monofocal IOLs (see American National Standard for Ophthalmics - Intraocular Lenses - Optical and Physical Requirements Z80.7 - 1984). The power for distance vision of the central zone of the three zone surface can be selected from 1 to 30 diopters. The second annular zone radius, together with the radius of the non-zone surface determines the power of the near vision as per the routinely used lens maker formula for monofocal IOLs. The power of the near vision zone provides additional power over the distance power of the central zone. This add power can be in the range of 2 to 5 diopters depending on the patient's eye dimensions and their need. The current state of clinical knowledge indicates that the preferred add power is in the range of 3.5-4.5 diopters. The third zone or peripheral zone radius together with the radius of the non-zone surface determines the focal length for image formation for distance vision from this zone. If the radius of this zone was made identical to that of the central zone for distance vision, then, because of what is referred to in the field of optics as spherical aberration from this peripheral zone, its image would be formed at a shorter focal length and thus, not coincident with the image formed by the central distance zone. If spherical aberration is not corrected, the distance image formed on the retina will be less sharp over a broad range of pupil sizes. In order to correct for this effect and make the two images coincident, it is necessary to increase the radius of the peripheral zone. The determination of the necessary radius of the peripheral zone is done by tracing a ray representing the peripheral zone to form the image on the optical axis at the same location for a ray representing the central zone. The height of the ray used to represent any zone is selected to best approximate the best focus image formed by that zone. The computation of the height of the representative ray is done such that it equally divides the area of the zone. The wave length selected for ray tracing can be in the range of 400-700 nm, but is preferably 550 nm, which represents photopic human vision. Ray tracing can be carried out by various methods known to those skilled in the art of optics, including application of the fundamentals of Snell's law and traditional geometry, or with readily available optical software packages such as GENII®, CODE V™, OSLO®, ACCOS V™, etc.

The radii of curvature of the three zones will vary depending on the type of material used in the optic of the lens. The material used will typically have a refractive index in the range of about 1.4-1.6. For example, when the optic is made of polymethyl methacrylate (PMMA), which has a refractive index of about 1.49, the zones can have radii of curvature as follows. The central zone's radius of curvature can be about 28.5 mm.

The second zone's radius of curvature can be between about 14.9-20.9 mm (this provides for about a 2.0-5.0 diopter increase over the distance vision power). The third zone's radius of curvature can be about 30.0 mm. The radius of curvature of the third zone differs from that of the central zone, both of which provide for distance vision, in order to correct for the spherical aberration such that rays passing through the central and third zones form a coincident image in aqueous.

If a soft acrylate copolymer, such as one disclosed in copending U.S. patent application Ser. No. 07/609,863 and the continuation-in-part Application entitled "Polymers and Their Use for Ophthalmic Lenses" filed on Feb. 17, 1992, which comprises 65 wt. % 2-phenylethyl acrylate (PEA), 30 wt. % 2-phenylethyl methacrylate (PEMA), 3.2 wt. % 1,4-butamediol acrylate (BDDA), and 1.8 wt. % 2-(3-methyl-2'-hydroxy-5'-methyl phenyl)benzotriazole is used to make an IOL of the present invention, then the central zone's radius of curvature can be about 32.0, and the second zone's radius of curvature can be about 24.7 mm-18.4 mm (2.0-5.0 diopter add). The third zone's radius of curvature can be about 33.3, again the radius of curvature of the third zone differs from that of the central zone to correct for spherical aberration.

FIGS. 1 and 2 illustrate a preferred embodiment of the present invention. FIG. 1 shows the anterior face of a single piece, PMMA intraocular lens comprising an optic and two haptics. The anterior face of the optic is comprised of three zones to provide for bifocal vision. The first zone (1) is a central zone for the provision of distance vision. It is about 1.8 millimeters in diameter. The second zone (2) is an annulus with an inside diameter of 1.8 mm and an outside diameter of 3.0 mm for the provision of near vision. The third zone (3) surrounds the second zone and extends from the outer diameter of the second zone to the edge of the optic for the provision of distance vision.

FIG. 2 represents a cross sectional view of the optic of FIG. 1 and shows the radii of curvature of the zones. The central zone (1) has a radius of curvature of about 28.5 mm for the provision of distance vision. The second zone has a radius of curvature of 17.4 mm for the provision of near vision (for about a 3.5 diopter increase over the distance vision power). The third zone (3) has a radius of curvature of about 30.0 mm for provision of distance vision. The radius of curvature for the third zone has been adjusted to correct for spherical aberration making light rays passing through the central and third zones form a coincident image in aqueous. The posterior surface of the optic (4) has a radius of curvature to provide for additional power so that the total distance vision power of the lens is from about 1 to about 30 diopters and the total near vision power is 3.0-35.0 diopters. Within these ranges, the near vision power is greater than the distance vision power by 2.0-5.0 diopters.

The lenses of the present invention can be used to replace the natural lens of the eye by a skilled clinician. The natural lens is most usually removed from the elderly upon their development of cataracts.

The present invention, having been fully described, is only limited as set forth in the following claims.

We claim:

1. A bifocal intraocular lens having an optic portion with a zone surface and a non-zone surface, the zone surface comprising a central zone comprising means for the provision of distance vision, having a diameter of